DESIGN, VALIDATION AND COSTING OF PRESSURIZED MF AND UF MEMBRANES FOR RECYCLED WATER

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Abstract
Our world is getting more and more thirsty for clean and safe water as the water cycle is squeezed on the demand side as well as on the supply side. Economic expansion and population growth require clean, reliable and uninterrupted water. Unfortunately, the sources of water have become either more polluted or increasingly more scarce due to climate change. Nowhere in the world have such realities been more exemplified than in Australia where extended droughts and lack of natural reservoirs have compounded the problem for many years.

Beyond conservation, new sources of water must be developed through the reuse or recycling of wastewater. Treatment technologies using advanced microfiltration (MF) and ultrafiltration (UF) membranes are well suited to a variety of wastewaters in providing new sources of water. This paper presents an overview of advanced pressurized-type membrane systems currently being used in Australia to produced Class A recycled water from wastewaters. Challenge tests with virus surrogates are presented for full-scale, membranes system validation to demonstrate regulatory compliance. Budgetary capital and operating costs of these membranes are given with respect to treatment capacity.

Keywords
Recycled water, MF, UF, secondary effluent, PVDF membranes, wastewater, LRV, virus validation

INTRODUCTION

Our world is getting more and more thirsty for clean and safe water as the water cycle is squeezed on the demand side as well as on the supply side. Economic expansion and population growth require clean, reliable and uninterrupted water. Unfortunately, the sources of water have become either more polluted or increasingly more scarce due to climate change. As a result, municipalities and industries are now demanding more recycled water to satisfy non-potable needs and lessen the burden on precious clean water supplies. Nowhere in the world has such realities been more exemplified than in Australia where extended drought and lack of natural reservoirs have compounded the problem for years.

State of the art pressurized MF/UF membrane treatments are a great fit for variable strength wastewaters in providing new sources of water. They are less sensitive to variations in feed water and can handle peak flows without deterioration in effluent quality. Membrane properties, characteristics and regulatory claims are detailed. Inexpensive membrane solutions are offered in pre-engineered, packaged or mobile designs. With increasing treatment sizes, additional savings will be realized with economy of scale resulting in even more affordable unit treatment costs. The “plug and play” designs allow rapid deployment and assembly on site. Regardless of treatment capacity, membrane systems continue to provide a finished water that often surpasses stringent water quality specs. Membrane technologies are now the treatment of choice for wastewater reuse.

This paper presents an overview of advanced membrane systems currently being used in Australia to produced Class A recycled water from wastewaters. Full-scale validation results using virus surrogates for both types of installed membranes are presented to demonstrate compliance with States’ Department of Health. Finally, budgetary capital costs and operating costs of these membranes are projected and compared with respect to treatment capacity.

MEMBRANE TECHNOLOGY

The Pall Microza® hollow-fiber microfiltration (MF) membrane is made of polyvinylidene fluoride (PVDF) polymer and has a uniform symmetrical construction throughout. The ultrafiltration (UF) membrane is made of polyacrylonitrile (PAN) with a double skin configuration. SEM photographs of the MF and UF membranes are shown in Figure 1.

The MF and UF modules come in a standard size of 2 m length x 0.2 m diameter in an ABS housing or shell. Each module contains over 6,000 fibers. The hollow-fiber MF is rated at 0.1 μm while the UF is rated at 100 kD. The MF has a high porosity and high permeability with a clean-water flux of 440 L/m^2/hr (LMH) at 100 kPa (20 C). For potable water treatment, the Pall MF has been approved by California Department of Public Health (CDPH) to operate at a flux of 204 LMH and at a maximum transmembrane pressure (TMP) of 310 kPa. For wastewater recycling, CDPH does not limit the flux or the operating TMP.

Regulatory agencies in the US have granted the MF membrane a log reduction credit (LRC) of 4 for *cryptosporidium oocysts* and a LRC of 0.5 for *MS2 bacteriophages*. When direct coagulation is applied, the MF has a LRC of 2.5 for viruses. The UF membrane has a credit of 4 for cysts and viruses.

Figure 1. SEM Photos of Pall Microza MF and UF Membranes

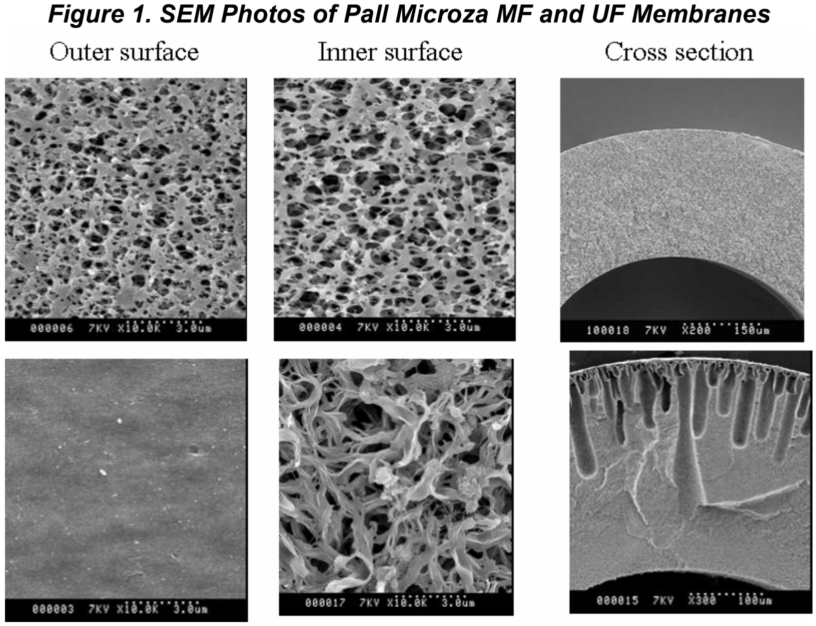


Table 1. Log Removal Credit (LRC) for MF and UF Membranes

LRC	MF	UF
Cryptosporidium	4	4
Viruses	0.5 2.5*	4

* coagulated water

MEMBRANES SYSTEM TECHNOLOGY

The Pall Aria™ membrane systems are engineered in pre-packaged models with treatment sizes up to 4 MLD (Figure 2) or can be custom designed to treat up to 300 MLD. An example of 80 MLD custom design system is shown below. The modules and racks designs have typically lower installation costs and faster delivery schedule than submerged or vacuum membranes systems. Identification of fiber breakages and repair for modules/racks designs are simple and can be done without removing the module from the racks and without the assistance of crane or any other specialized equipment. Broken fibers can be identified and repaired in about 30 min.

Figure 2. Pre-engineered and Large Custom Design Aria Systems

A unique feature of the Aria systems is the ability to control fouling through an operating strategy called "enhanced flux maintenance" (EFM) where a chlorinated solution at pH 11 is recirculated through the modules at set intervals (daily or weekly), for a period of 30-40 minutes. The EFM process is fully automated and does not affect the life of the membranes. EFM desensitizes the membranes from variations in water quality and allows the membranes to operate in an almost-clean condition and therefore lower average operating TMP. EFM is much more effective than the industry standard chemical-enhanced backwash (CEB) because it has a longer exposure time, but at the same time generates less chemical wastes through recirculation and re-use of the chemicals.

OVERVIEW OF RECYCLED WATER IN AUSTRALIA

Wastewater feeds are highly variable depending upon upstream treatment process, location and local regulations. Matching a membrane technology either MF or UF to each individual project requirement can ensure the best affordable and compliant recycled scheme with the least risk to public health.

Western Corridor Recycled Water Project

Brisbane City constructed a Pall MF membrane plant to treat the effluent of 15 MLD from a biological nutrient removal (BNR) plant. Currently the majority of the wastewater from Luggage Point Wastewater

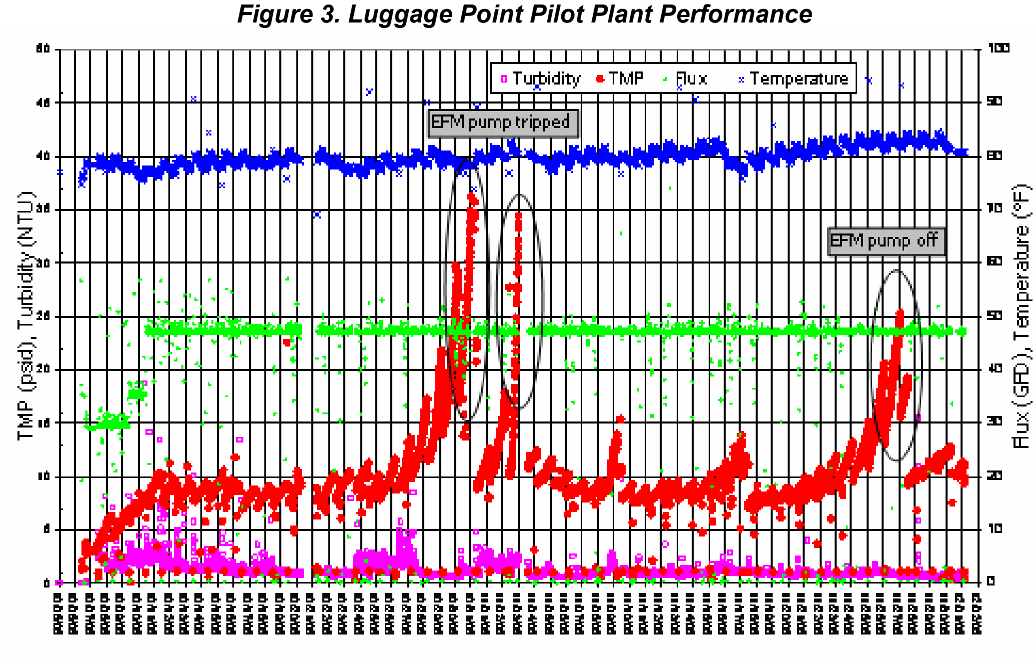
Treatment Plant goes out into Moreton Bay, but a small proportion is "recovered" and further treated with MF and RO and piped to a neighboring refinery for cooling water and boiler feed.

The Pall MF system was designed at a flux of 45 LMH with 6 racks (including 1 standby) and 66 modules per rack. Since 2000, the system has operated with an average TMP of 60 kPa and 4-6 weeks CIP intervals. The plant was not designed with the EFM feature.

Late 2006, a Pall pilot plant was installed side-by-side with the full-scale plant to compare performance using new operating protocols with EFM. The pilot was operated at 80 LMH for over 6 weeks without the need for CIP. A daily EFM with 500 ppm NaOCl and weekly EFM with 1,000 ppm citric acid were set for this run. EFM is essential to maintain low membrane TMP. For example, on two occasions when the EFM chemical pump malfunctioned, spikes in TMP were observed. But as soon as the EFM was restored, the operating TMP dramatically came down and stabilized.

On average, the TMP is around 70 kPa (Figure 3). Since the installation of the Pall MF plant 8 years ago at Luggage Point, there have been advances in operating protocols which can mitigate fouling and promote a better performance by 80% higher flux and similar TMP range. Running the pilot plant side by side provided beneficial new operating regimes for improvements on the existing installation.

Figure 3. Luggage Point Pilot Plant Performance



The Luggage Point AWT expansion was built to provide 85 MLD of purified recycled water. Construction started in 2007, the plant is fully operational since December 2008. By combining coagulation, MF and RO technologies, Luggage Point AWT delivers Class A+ recycled water power stations and industrial users. Recycled water can be used for Indirect Potable Reuse (IPR) via outlet into the Wivenhoe dam. This is currently the largest MF plant in Australia designed with 11 racks of 122 MF modules/rack providing a total filtration area of over 67,000 m^2 (Figure 4).

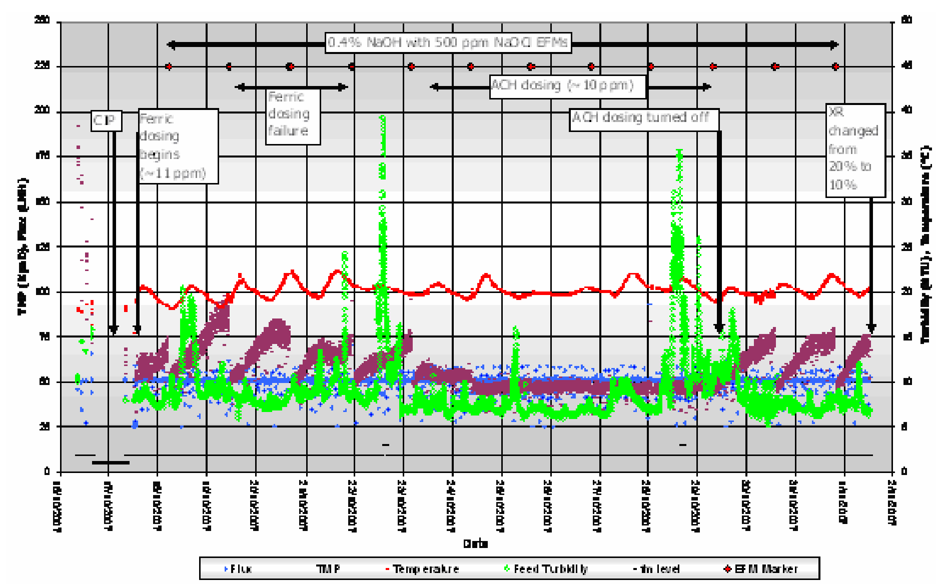
Figure 4. Luggage Point 85 MLD MF Capacity

Eastern Irrigation Scheme (EIS)

The Carrum Downs facility which is part of Water Infrastructure Group's Eastern Irrigation Scheme treats secondary effluent from Melbourne Water's Eastern Treatment Plant. It was recently upgraded with additional 20 MLD of Class A+ recycled water. EIS provides recycled water to over 60 customers for horticultural, recreational and residential non-potable use.

Prior to the installation of new PVDF UF membranes, pilot tests were conducted to qualify their performances. It was determined that the new UF membranes were capable of operating at 50 LMH on highly variable wastewater. Ferric chloride was initially dosed as a coagulant with membrane TMP averaging 75 kPa. After switching to a low dose of aluminum chlorhydrate (ACH) coagulant, the TMP immediately flattened out and stabilized around 50 kPa. Without ACH, the TMP rose frequently with average of 65 kPa (Figure 5). After more trials, the optimum ACH dose was found to be 1.5 mg/L.

Figure 5. Carrum Downs Pilot Plant Performance



Full-scale validation of this advanced treatment plant comprising 4 racks of 116 UF membranes/rack (Figure 6) was carried out by Water Infrastructure Group using MS2 phages (f-RNA phage SA). Challenge tests were conducted on 1 rack at full capacity, ½ capacity and full capacity with 8 artificially cut fibers. The virus log reduction values (LRV) of the UF membranes are all greater than 7 as detailed in Table 2. The achieved LRV for virus exceeds the requirement of 4-logs credit given by States' regulatory agencies. It must be noted that during the challenge tests, both pre-chlorination and ACH coagulation were switched off.

Figure 6. Carrum Downs 20 MLD UF Capacity

Table 2. Full-Scale Virus LRV Based on Challenge Tests (Courtesy of Water Infrastructure Group)

Rack Flowrate	4 MLD	2 MLD	4 MLD +8 cut fibers
LRV (median)	7.93	7.93	7.79

Surbiton Park

The Western Water/Water Infrastructure Group Surbiton Park involves 2 MF skids (40 modules/rack) which treat secondary effluent to supply up to 5 MLD of Class A recycled water to the Eynesbury Township and for golf course, toilet flushing and car washes. This plant uses coagulation with MF to achieve high virus removal followed by UV and chlorine disinfection. The coagulation process was hydraulically and chemically optimized by pH and alkalinity adjustments. Enhanced flocs formation resulted in high, average virus LRV across the MF membranes (Figure 7).

Figure 7. Surbiton Park 5 MLD MF Capacity with Enhanced Coagulation

Full-scale challenge tests with MS2 phages were conducted for the combined treatment train of coagulation and 2 MF racks. Both trains were operated at maximum capacity with coagulation throughout the challenge tests. The results showed that the virus LRV were greater than 3.5, as shown in Table 3.

Table 3. Full-Scale Virus LRV Based on Challenge Tests (Courtesy of Water Infrastructure Group)

Rack Flowrate	Rack A 2.5 MLD	Rack B 2.5 MLD
LRV (median)	3.87	3.85

Wetalla AWTP

As part of the extensive upgrade of the Wetalla Treatment Plant in South East Queensland, an Advanced Water Treatment Plant was recently commissioned to produce 11 MLD of Class A recycled water using 4 separate MF skids and racks with 44 modules per rack, as seen in Figure 8. Pretreatment involves dosing acid while post membrane treatment involves extended contact time chlorination.

Most of the produced Class A recycled water is discharged under EPA license to Gowrie Creek in the environmentally sensitive Darling River System. About half of the water is taken by the New Acland Coal Mine via a 45 km pipeline for coal washing.

Figure 8. Wetalla 11 MLD Plant Layout

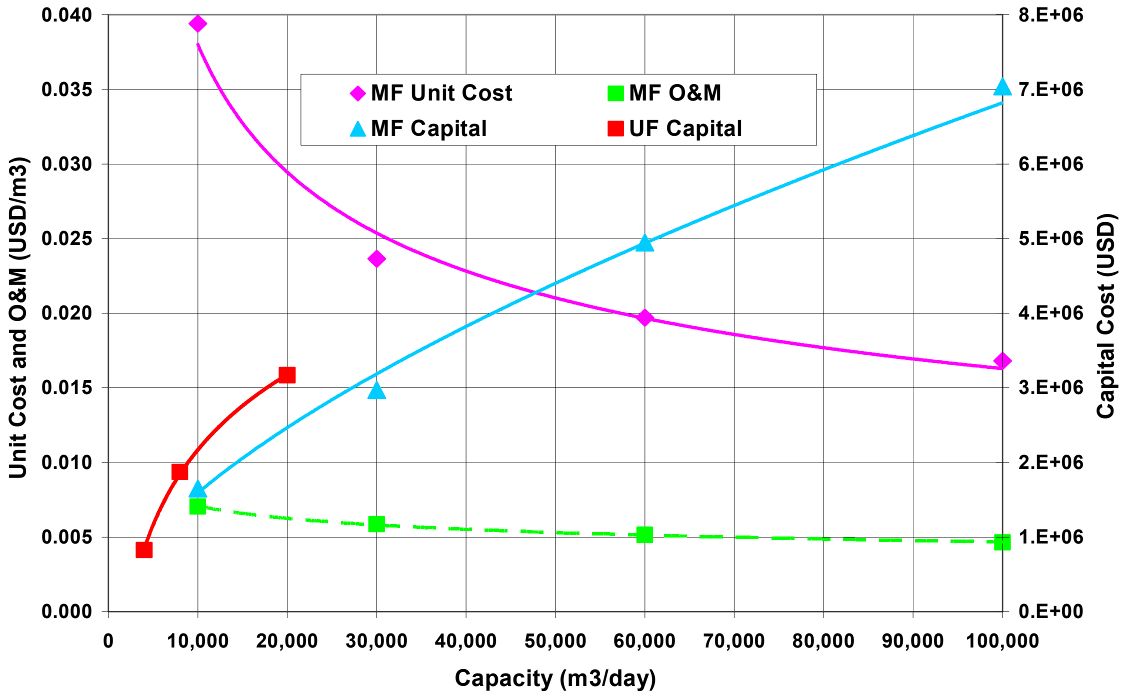
COST OF RECYCLED WATER VS TREATMENT CAPACITY

This section provides guidelines with respect to cost of recycled water using microfiltration as a function of treatment capacity. The MF capital cost does not include replacement modules; it does include redundancy built into the system. The evaluation was calculated based on a MF flux of 75 LMH, 20-yr plant life and membrane lifetime warranty of 10 years. For the UF evaluation, actual sale prices of the systems are used.

The MF unit cost is capital cost annualized at an interest rate of 6% which does not include membranes replacement cost. The operating and maintenance (O&M) costs take into account energy for pumps, compressors, heating and chemical consumption for EFM/CIP. As the treatment capacity increases, there is an economy of scale and the treatment cost of recycled water decreases. For example, a 20,000 m^3/day MF plant will provide treated water at USD 0.029/m^3 while an 80,000 m^3/day plant will provide treated water at USD 0.017/m^3 (Figure 9). The capital cost of a UF plant is higher than MF plant because of UF lower design flux, thus, requiring a higher number of modules.

The O&M costs are fairly independent of treatment capacity and typically range between USD 0.005-0.007/m^3. There is no significant difference in O&M costs between MF and UF.

Figure 9. Cost of Recycled Water and Treatment Size



CONCLUSION

Australia has embarked on a very aggressive strategy of recycling water to limit demand on drinking water supplies and to minimize environmental damage to waterways and bays. Advanced membrane treatment technologies are an integral part of its strategy producing purified Class A+ recycled water which is safe, clean and sustainable. Membrane plants are validated by challenge tests and integrity-tested regularly to ensure performance and minimize risk to public health.

Pre-engineered, packaged systems have driven down the cost of recycled water. As treatment capacities become increasingly larger, further savings are realized with economy of scale thereby making even custom-designed plants more and more affordable. In multiple barrier approach to water recycling (secondary, membrane filtration, RO, storage, AOP, disinfection), MF membrane may be used as long as the total treatment train meets Australian Guidelines for Water Recycling. In situations where the LRV for virus cannot be met with MF, UF membranes are required. Capital costs of UF membranes are usually higher because of their lower operating flux and shorter warranties. O&M costs are similar for both membranes. O&M are kept very low with either coagulation of highly variable feeds or by enhanced flux maintenance (EFM) process, a unique feature of the described MF and UF membrane plants.

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